Echo in Heart Failure

THE UNIVERSITY OF CHICAGO
CARDIAC IMAGING CENTER

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Heart Failure: Definition

A clinical syndrome that results from impairment of ventricular filling or ejection of blood. Manifestations include dyspnea and fatigue, exercise intolerance, fluid retention, which may lead to pulmonary +/- splanchnic congestion +/- peripheral edema. Some patients have exercise intolerance but little fluid retention, others complain primarily of edema, dyspnea, or fatigue

There is **no single** diagnostic test for HF. It is a clinical diagnosis based on a the history and physical examination

Yancy et al 2013 ACCF/AHA Heart Failure Guideline

Heart Failure: Prevalence

- Estimated 23 million people with HF worldwide
- In the US: 670 000 cases diagnosed/year
- 1 million hospitalizations and 3.4 million outpatient visits
- Rate of rise in HF cases has outpaced the rate of transplantation

Prevalence of Common Cardiovascular and Lung Diseases, U.S., 2004, NHLBI report
Death from specific cardiovascular, Lung and Blood Diseases, U.S., 2004 NHLBI report

Mechanical Assist Devices

A valuable option for patients with end stage **systolic** heart failure (Stage D)

ESC Definition of Advanced HF

1. Severe symptoms of HF with dyspnea and/or fatigue at rest or with minimal exertion (NYHA class III or IV)
2. Episodes of fluid retention (pulmonary and/or systemic congestion, peripheral edema) and/or reduced cardiac output at rest (peripheral hypoperfusion)
3. Objective evidence of severe cardiac dysfunction shown by at least 1 of the following:
   a. LVEF <30%
   b. Pseudonormal or restrictive mitral inflow pattern
   c. Mean PCWP >16 mm Hg and/or RAP >12 mm Hg by PA catheterization
   d. High BNP or NT-proBNP plasma levels in the absence of noncardiac causes
4. Severe impairment of functional capacity shown by 1 of the following:
   a. Inability to exercise
   b. 6-Minute walk distance ≤300 m
   c. Peak $\dot{V}O_2$ <12 to 14 mL/kg/min
5. History of ≥1 HF hospitalization in past 6 mo
6. Presence of all the previous features despite "attempts to optimize" therapy, including diuretics and GDMT, unless these are poorly tolerated or contraindicated, and CRT when indicated

Why offer an LVAD?

- Wait times for cardiac transplantation are long
- Large numbers of patients with end-stage heart failure
- 1-y survival on LVAD support awaiting transplant ~55-85%
- >30 000 LVADs are implanted world-wide

LVADs: Clinical Indications

1. Bridge-to-Transplantation (BTT)
   - Duration of Support: 6 ~ 12 months
   - Maximize survival until transplant
2. Destination Therapy (DT)
   - Duration of support is indefinite
   - Purpose: maximize functional capacity and quality of life
   - 1-y survival approaching 80%
3. Myocardial Recovery + Potential Explant
   - Maximize LV reverse remodeling

LVAD Circuit

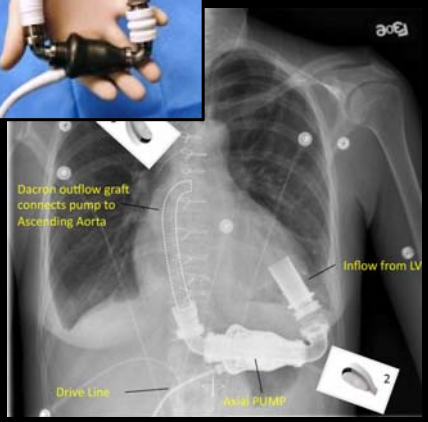
Removal of blood from LV apex return blood to aorta via graft

Three main internal components to LVAD:

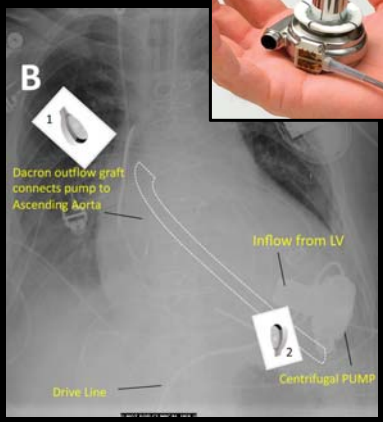
1. Inflow cannula at LV apex
2. Mechanical impeller
3. Outflow graft connected to the ascending aorta

Rasalingam R. J Am Soc Echocardiogr 2011;24:135-48

HeartMate II



HVAD (HeartWare)



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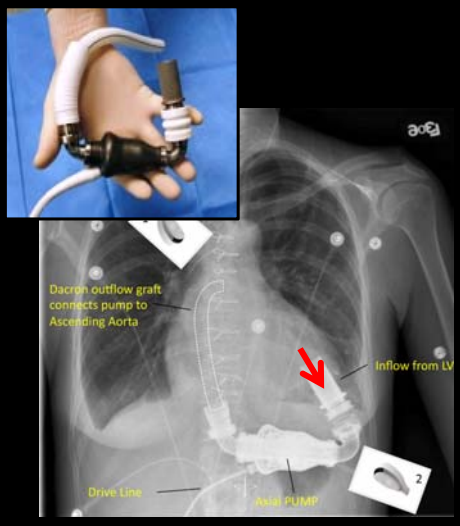

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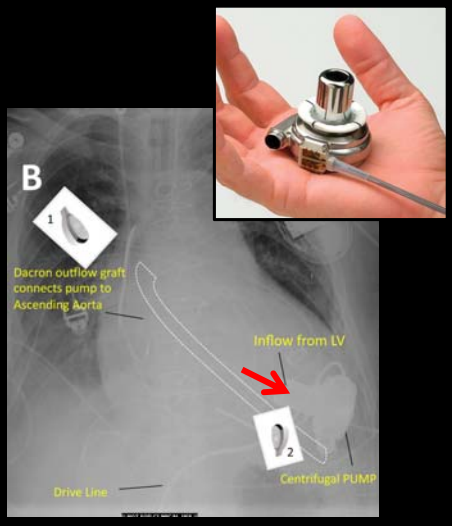

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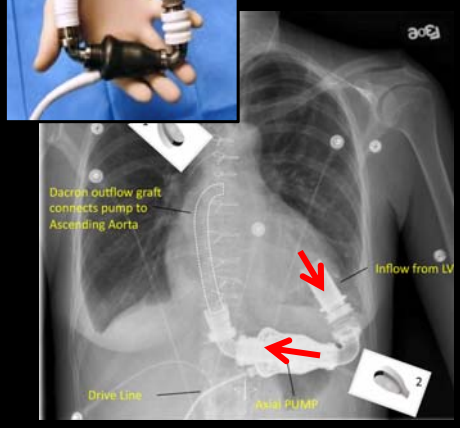
HeartMate II



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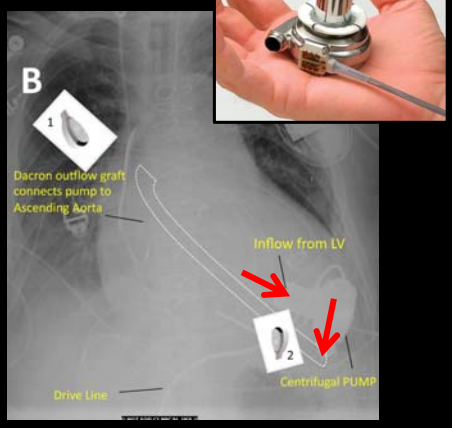

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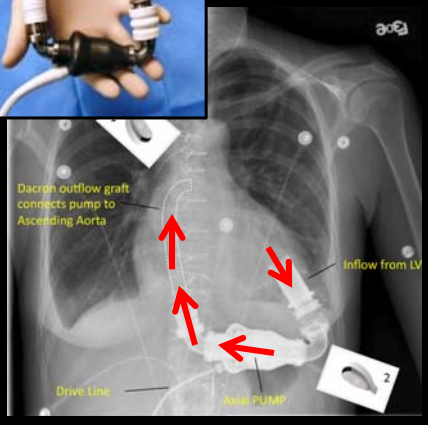

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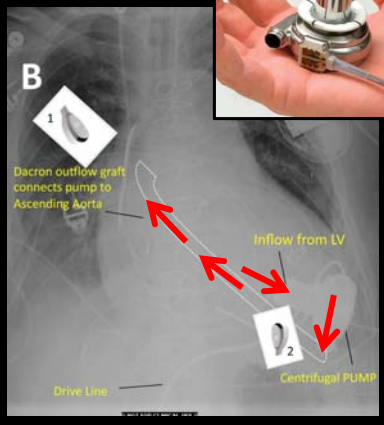

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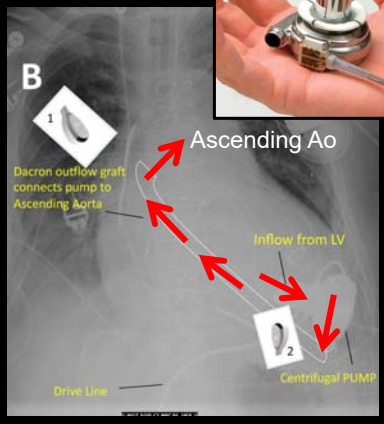
HeartMate II

HVAD (HeartWare)



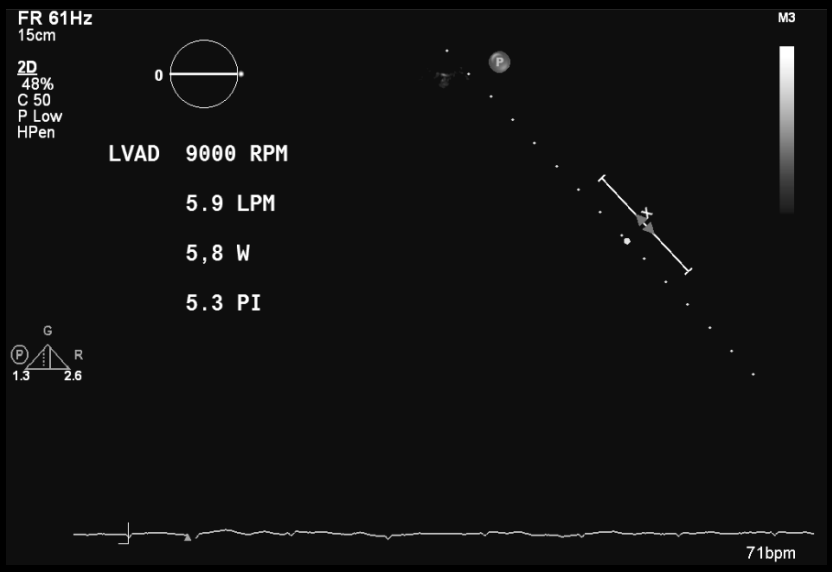
Rasalingam R. J Am Soc Echocardiogr 2011;24:135-48

ECHO: Clinical Indications

1. Surveillance
   - Drift from baseline echo
2. Determine optimal device settings
   - With or without speed changes
   - To select the optimal LVAD speed setting
3. Assess complications
   - Thrombosis
   - Inflow/outflow cannula obstruction
4. Assessment of LV recovery

The Surveillance Echo

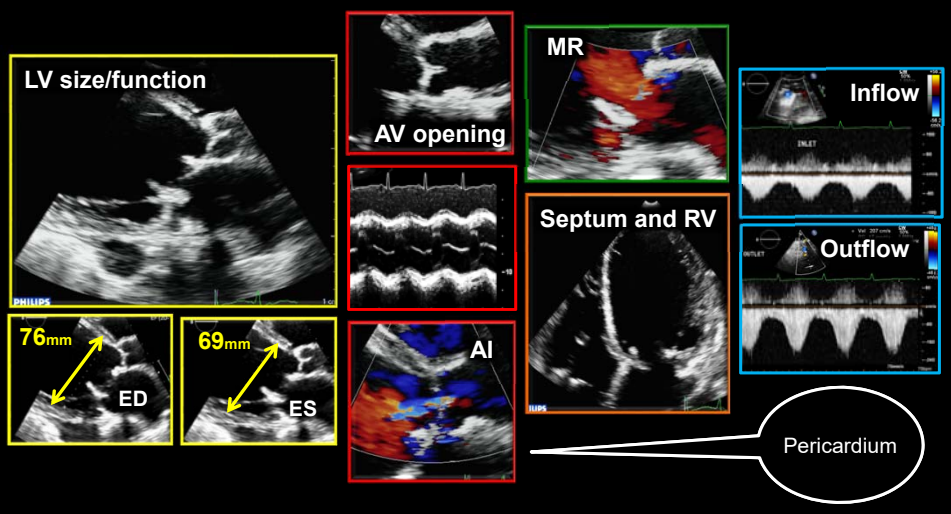
LVAD Parameters



LVAD Evaluation

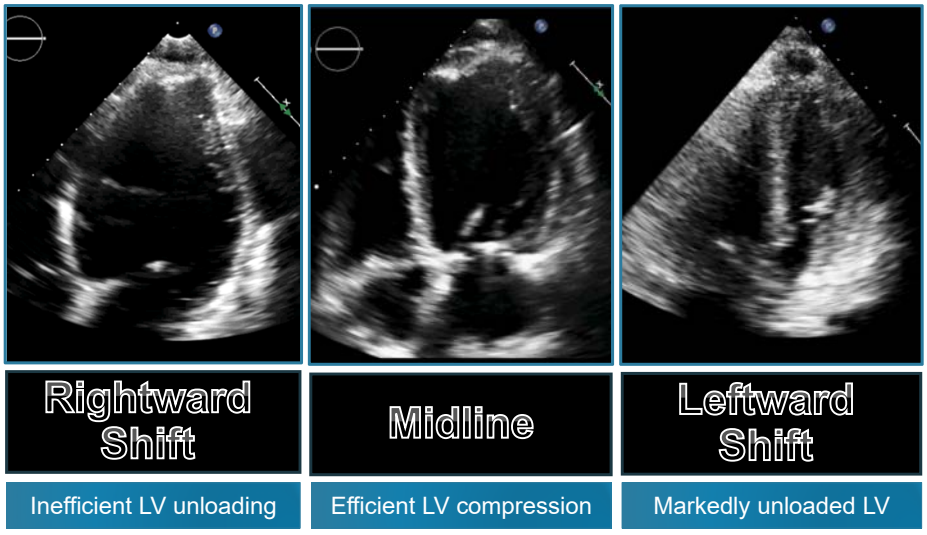
1. LV size
2. Aortic valve opening
3. Aortic insufficiency
4. Inter-ventricular septum position
5. Right ventricle size and function
6. Mitral regurgitation
7. Inflow cannula
8. Outflow cannula
9. Thrombosis
10. Pericardium

LVAD Surveillance Echo



Inter-ventricular septum

Position of Inter-ventricular Septum

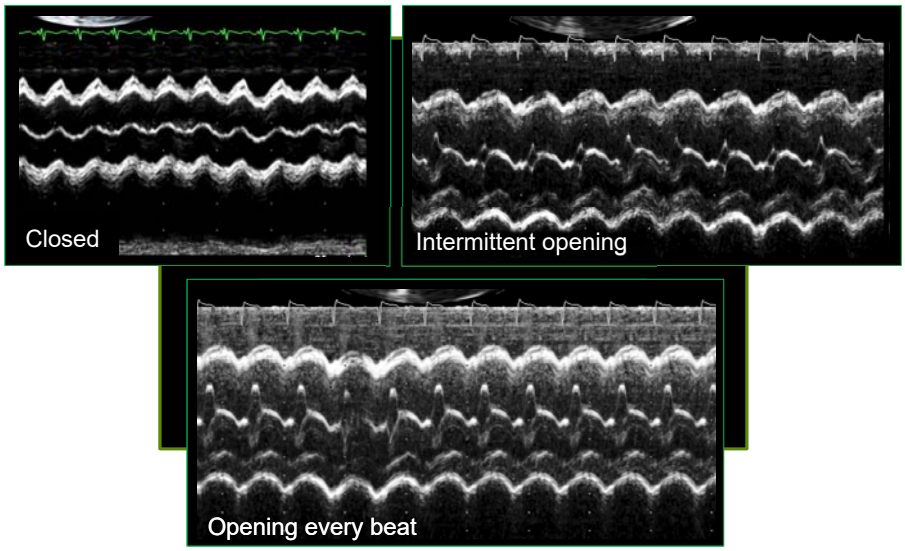


Aortic Valve Opening

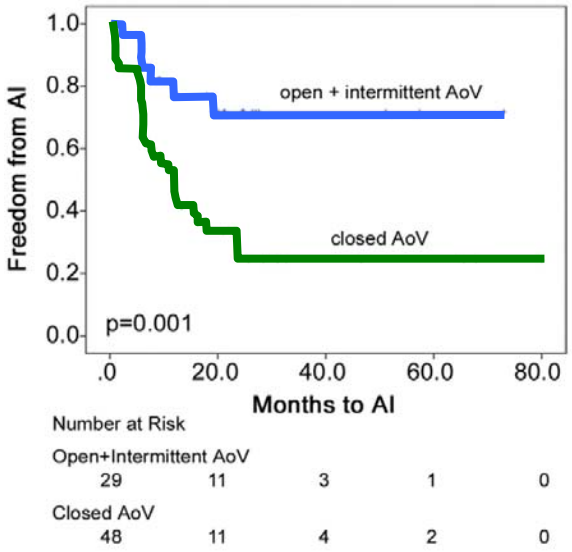
Aortic valve opening: 2D Echo

Closed	Intermittent opening	Opening normally

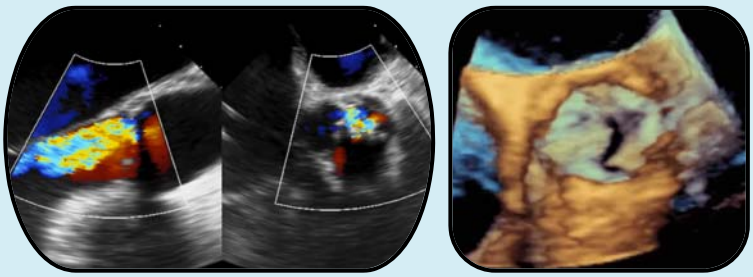
Aortic valve opening: M-mode Echo



Impact of Aortic valve opening



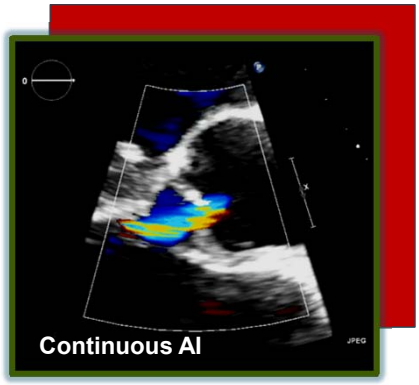
Aggarwal A. Ann Thorac Surg 2013;95:493–9



Aortic Insufficiency

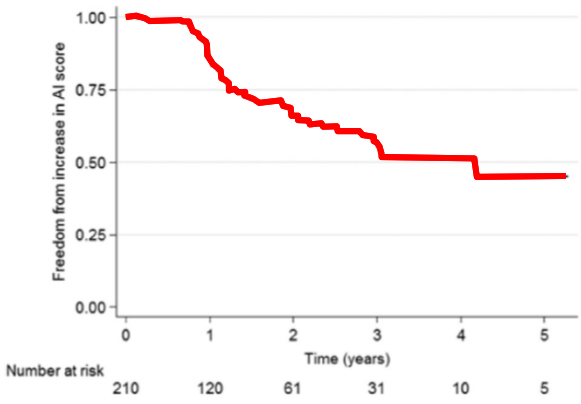
Aortic Insufficiency

1) Often occurs during both systole and diastole (pan-cyclical) and not only during diastole
2) Overall volume load that the ventricle sees is greater

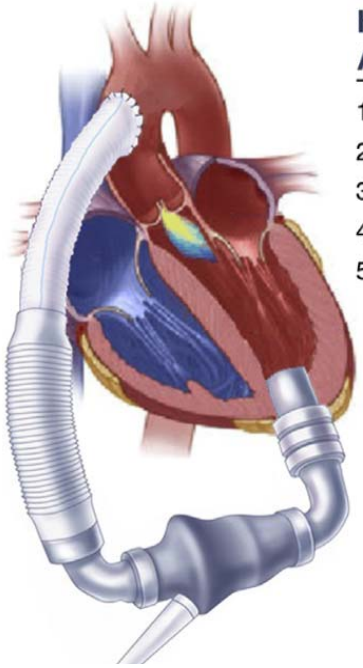


3) Eccentric and often poorly measured by traditional echocardiographic measures such as vena contracta and PISA

Time Course of Aortic Insufficiency



N = 237 patients with HeartMate II CF-LVADs
32 patients had mod or severe AI

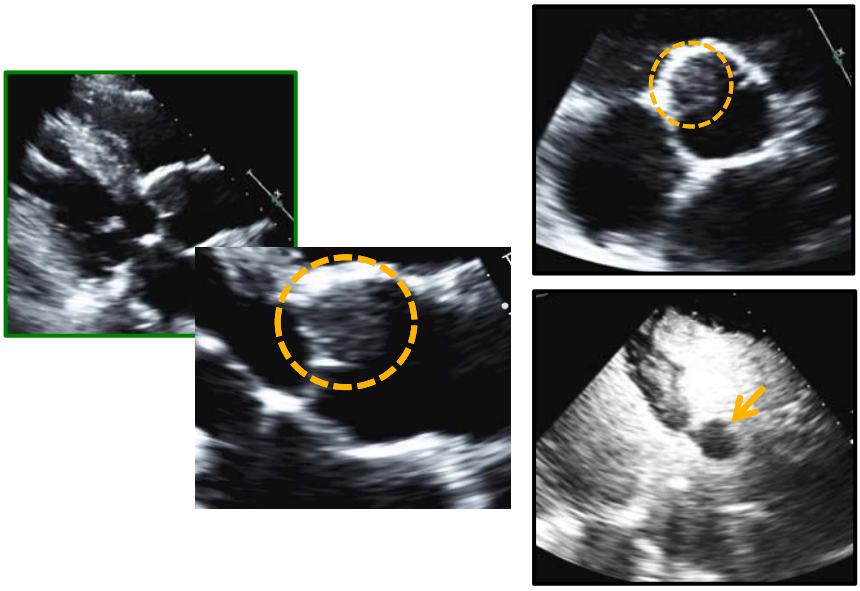


Histopathological Changes Leading to AI in cf-LVADs

1. Increased local fibrosis and thrombus formation
2. Aortic root remodeling and dilatation
3. AV degeneration and remodeling
4. AV commissural fusion
5. AV leaflets malcoaptation

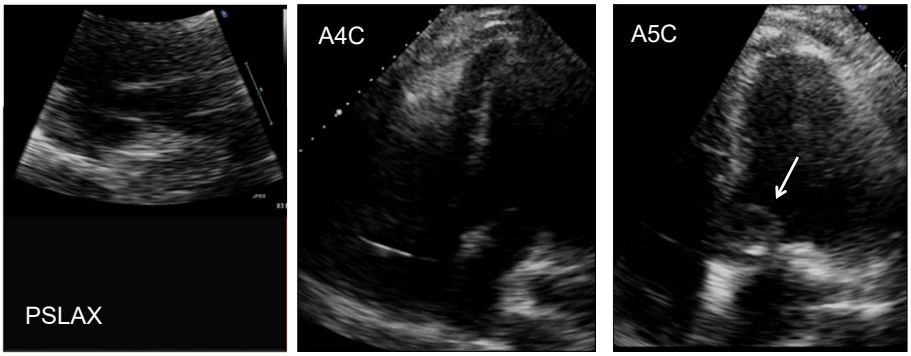
Thrombosis

Aortic Root Thrombosis

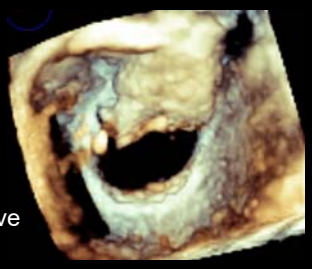


Other Thrombosis

50 year-old man 1 month status post HeartMate II LVAD. He was ready to go home after a lengthy admission. This echo was done prior to discharge.

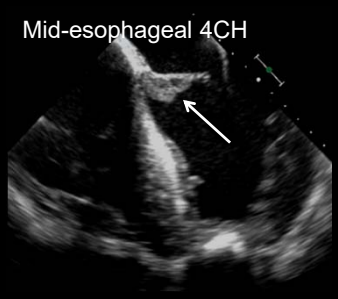


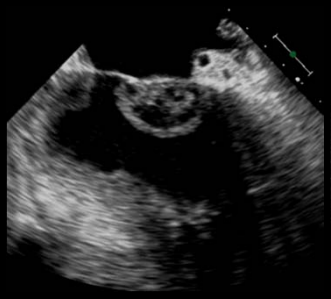
Other Thrombosis



LV perspective

Mid-esophageal 4CH



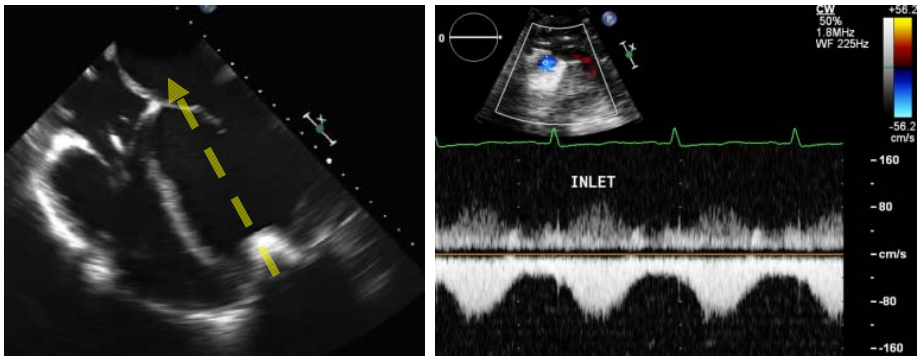


LAX

Inflow cannula

- Malposition
- Occlusion
- Thrombosis

The Normal Inflow Cannula

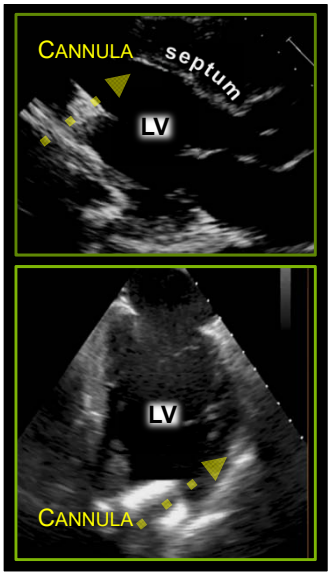


Inflow cannula is usually positioned in the LV apex and oriented within the LV toward the mitral valve

The Abnormal Inflow Cannula

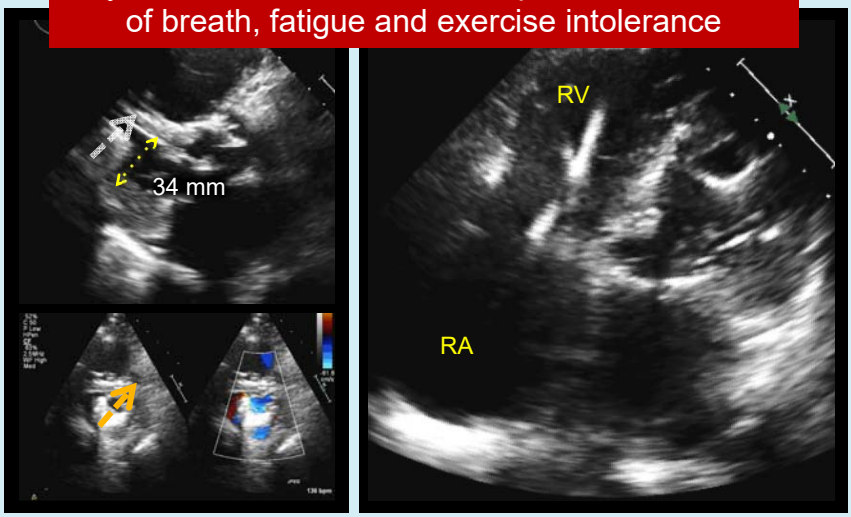
Mechanisms of inflow cannula obstruction

- Thrombus
- Inlet occlusion by trabeculations
- Cannula angulation into the myocardium
- Malposition due to LV under-filling



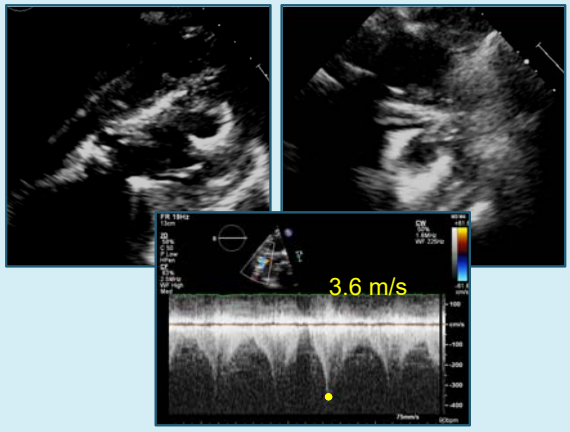
The Abnormal Inflow Cannula

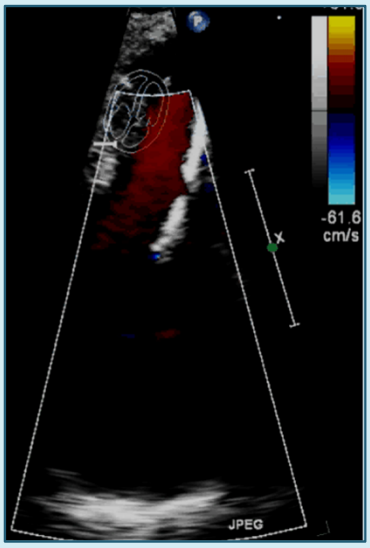
74 year-old F with an LVAD complains of shortness of breath, fatigue and exercise intolerance



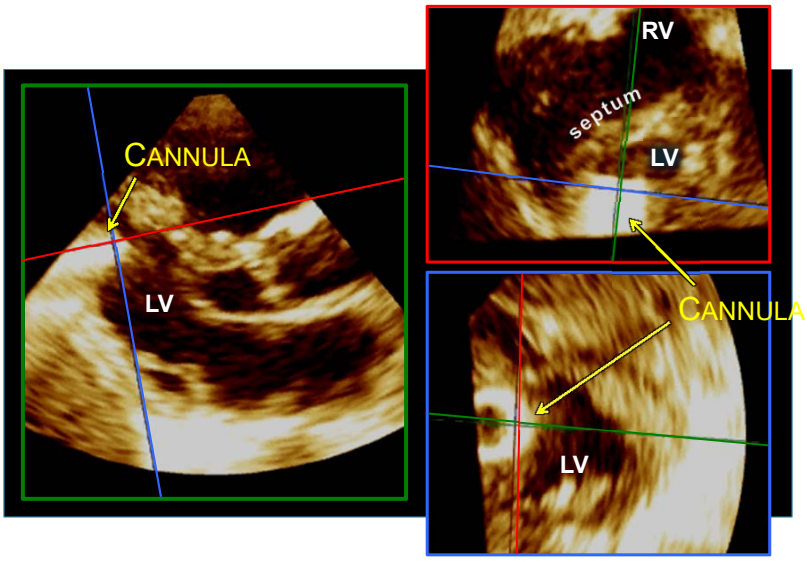
The Abnormal Inflow Cannula

74 year-old female with an LVAD complains of shortness of breath, fatigue and exercise intolerance





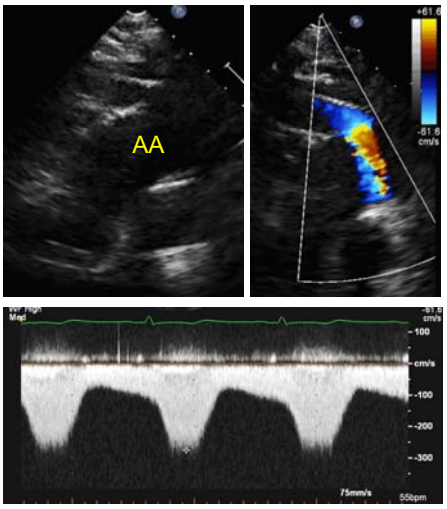
The Abnormal Inflow Cannula



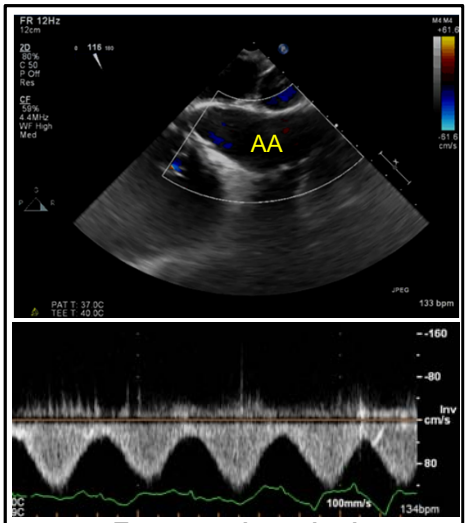
Outflow cannula

- Kink
- Obstruction
- Thrombosis

The Normal Outflow Cannula



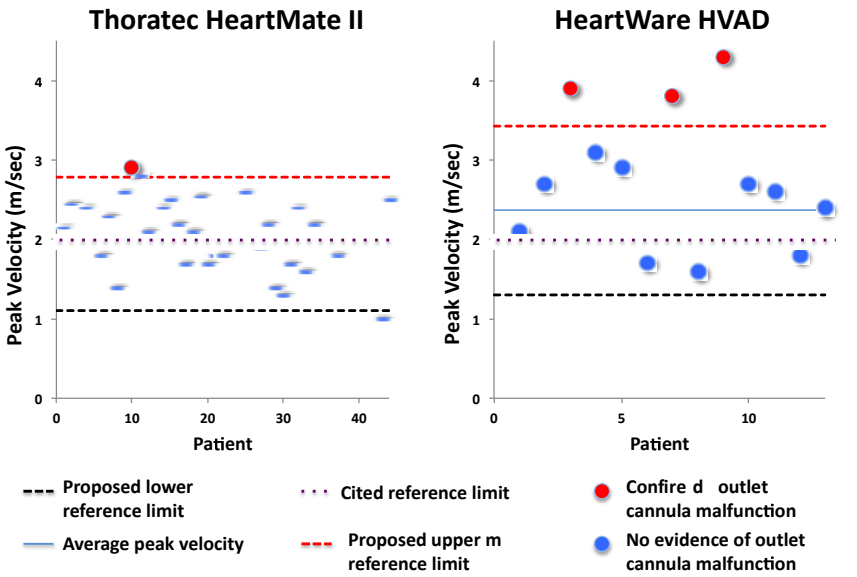
Transthoracic echocardiogram



Trans-esophageal echo

Normal reference for outflow cannula peak velocities depend on LVAD type

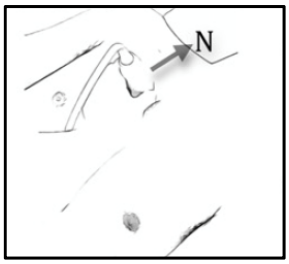
- 57 patients with LVADs:
  - Thoratec HeartMate II (HMII) (N= 44)
  - HeartWare (HW) (N= 13)
- LVAD outflow peak velocities were measured with Doppler echocardiography (TTE) from the right parasternal window to establish the average velocity as well as the upper and lower normal reference limit (defined as ± 2SD around the mean).
- The upper reference limit was then used as a screening threshold for outflow cannula malfunction.



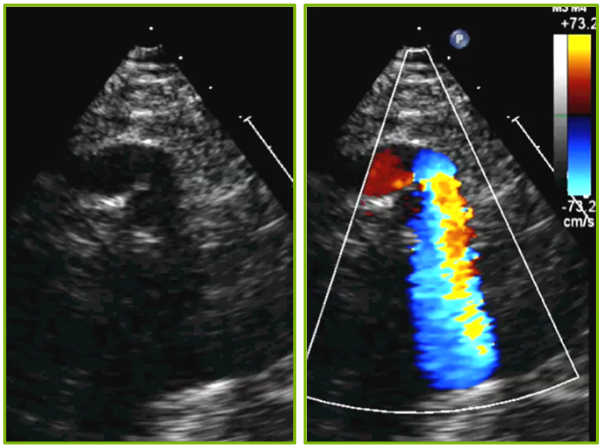
1.94 ± 0.42 m/sec, with an upper and lower reference limits of 2.78 and 1.10 m/sec,

2.36 ± 0.53 m/sec, with an upper and lower reference limits of 3.42 and 1.3 m/sec

Abnormalities in the outflow cannula: Case 1

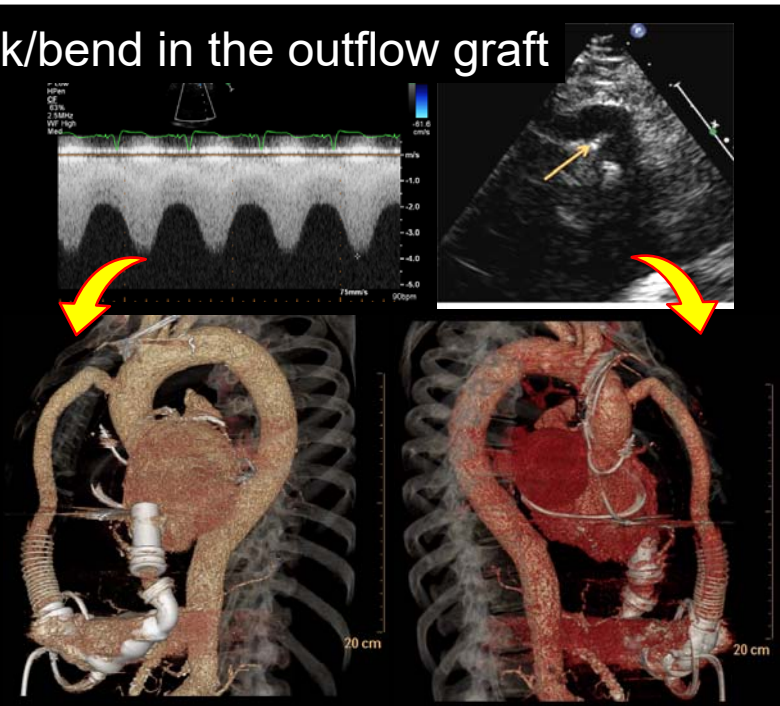


61 year-old man s/p HMII for ICM. Peak outflow cannula velocity of 3.9 m/s on 13d follow-up echo

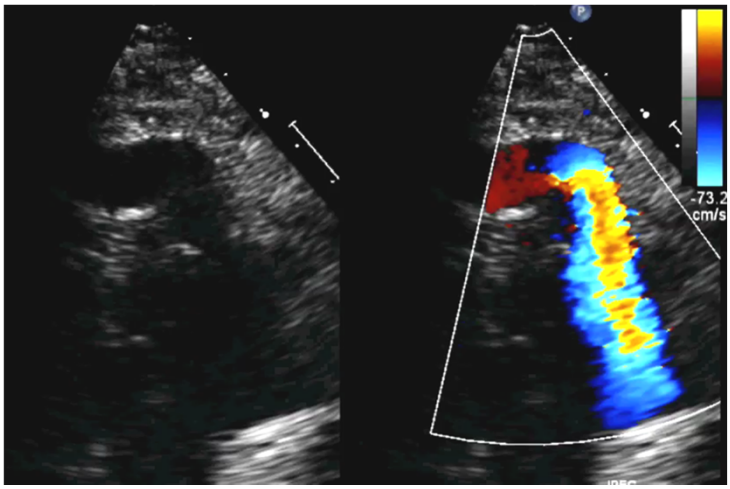


Outflow cannula velocity 3.9 m/s

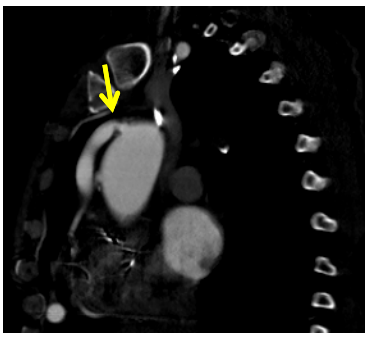
Kink/bend in the outflow graft

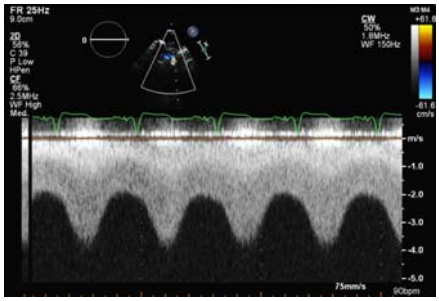


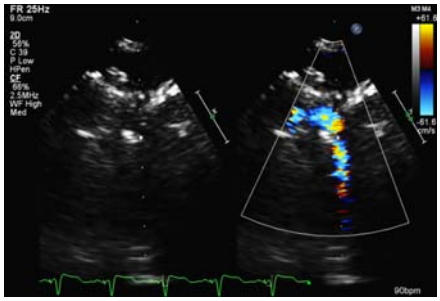
Abnormalities in the outflow cannula: Case 2



Stenosis in the outflow graft



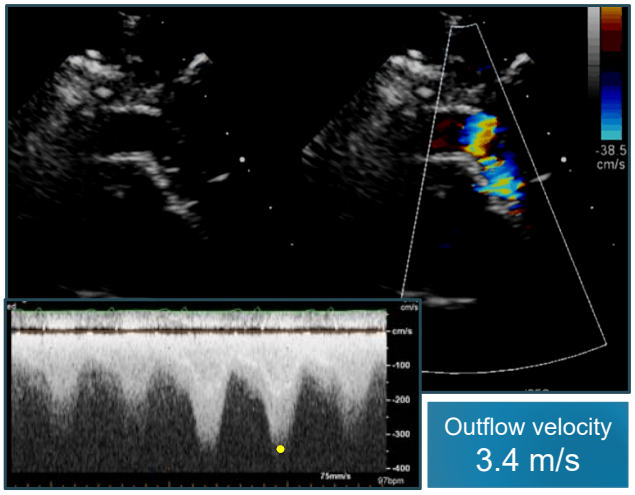




Abnormalities in the outflow cannula: Case 3

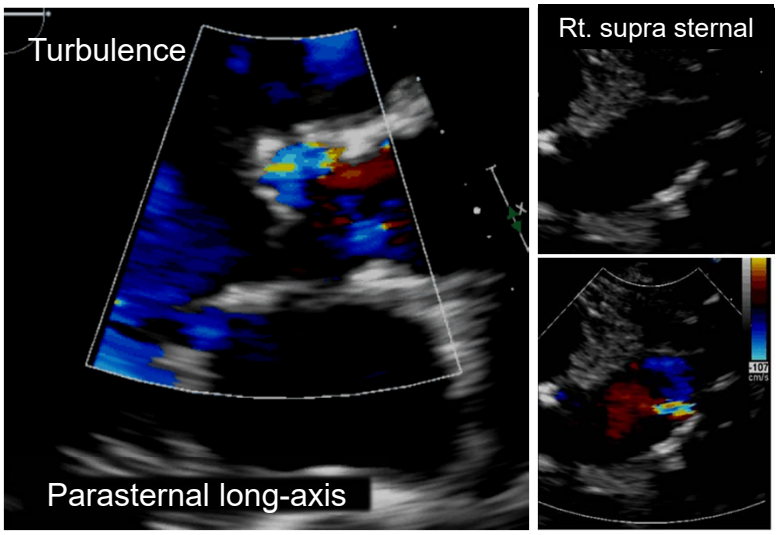
48 yo woman status post HeartWare LVAD for ICM as BTT. Admitted with shortness of breath/chest pain

RHC:
RAP = 23 mmHg
PAP = 52/34
mPAP = 40 mmHg
PCWP = 29 mmHg
SVR = 1644 dynes/sec/cm-5

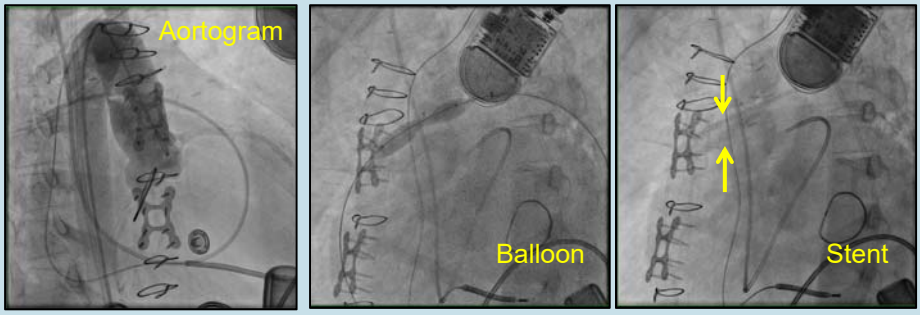


Outflow velocity
3.4 m/s

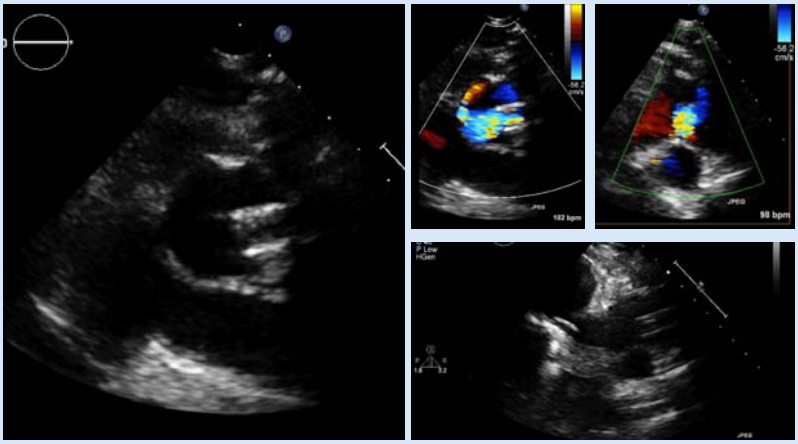
Abnormalities in the outflow cannula: Case 3



Abnormalities in the outflow cannula: Case 3



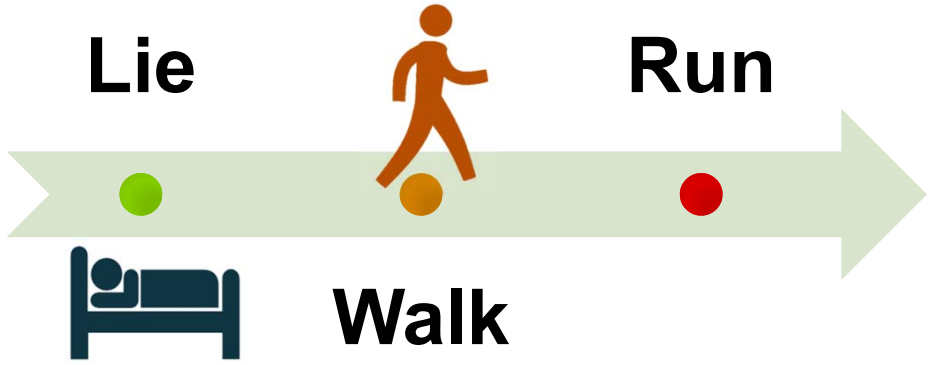
Abnormalities in the outflow cannula: Case 3



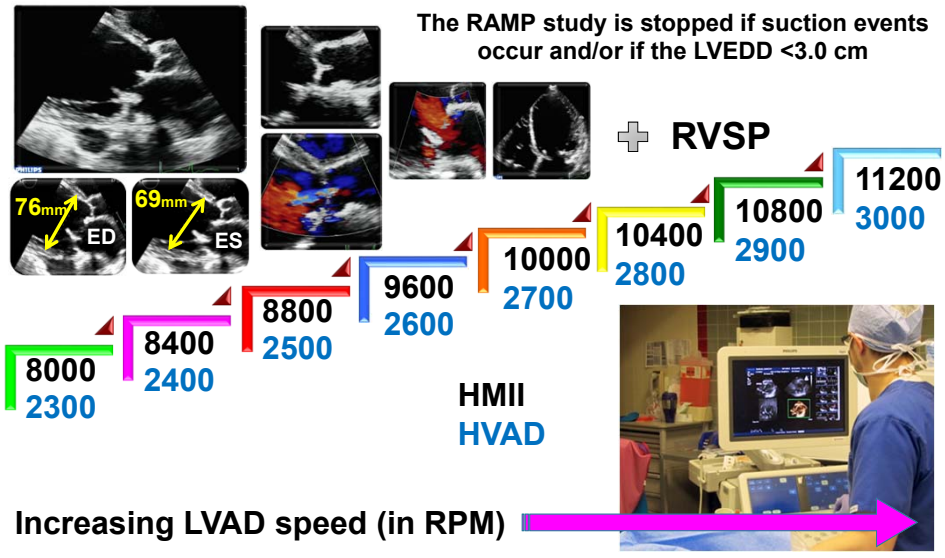
Post stent echo

LVAD speed optimization

Cardiac Output



The Ramp Study

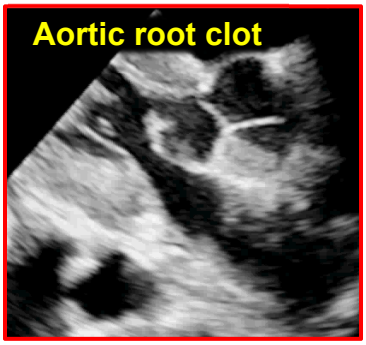


The RAMP Study

1. Optimize device speed without compromising cardiac function:
   i. Mean arterial **BP >65 mmHg**
   ii. Maintain **inter-ventricular septum** position in **midline**
   iii. **Intermittent** aortic valve opening
   iv. No more than **mild mitral regurgitation**
2. Evaluate for LVAD malfunction such as device-related thrombosis

Pre-RAMP Considerations

Ensure:
- INR >1.8
- PTT >60
- No LV thrombus
- No aortic root thrombus



RAMP test protocol

Table 1 Ramp Test Protocol (for HeartMate II)

Speed, rpm	PI	Power	Flow	BP	HR	LVEDD	LVESD	AV Opening	AI	MR	RVSP
8,000											
8,400											
8,800											
9,200											
9,600											
10,000											
10,400											
10,800											
11,200											
11,600											
12,000											

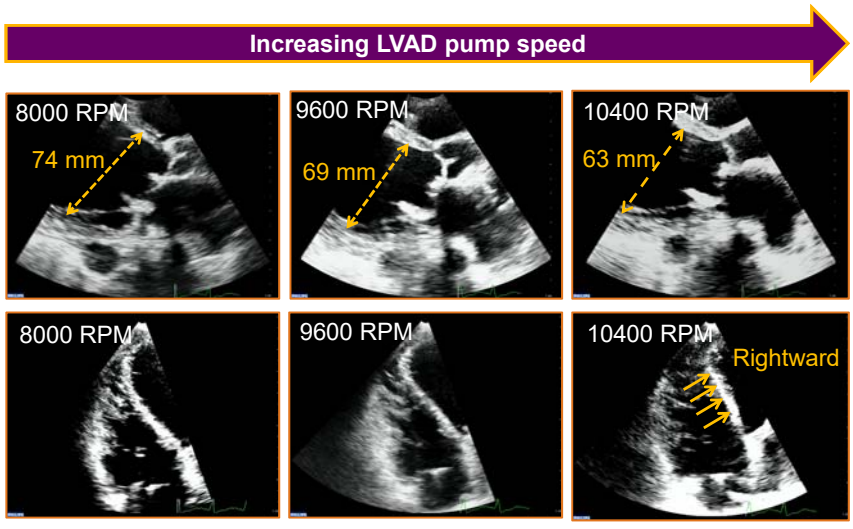
LVAD parameters

Patient parameters

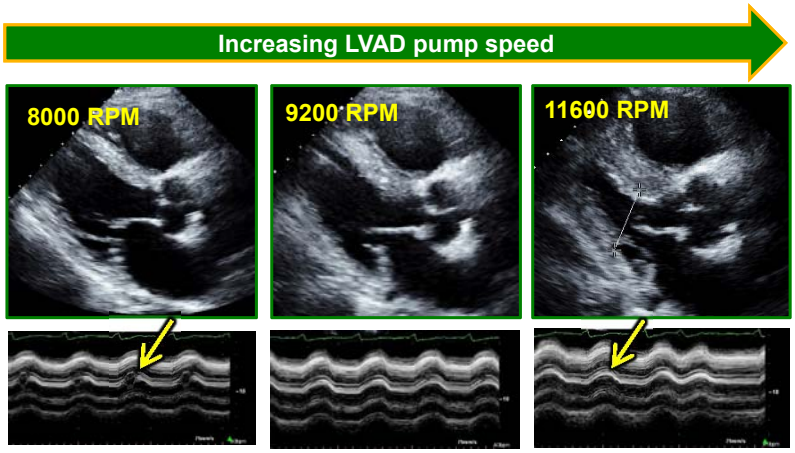
Echo parameters

Similar ramp test protocol was developed for the Heartware device.
AI = aortic insufficiency; AV = aortic valve; BP = blood pressure; HR = heart rate; LVEDD = left ventricular end-diastolic diameter; LVESD = left ventricular end-systolic diameter; MR = mitral regurgitation; PI = pulsatility index; RVSP = right ventricular systolic pressure.

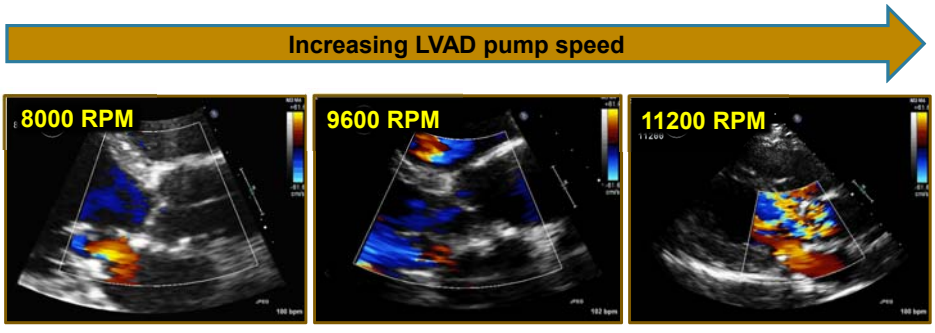
Optimization of LV unloading



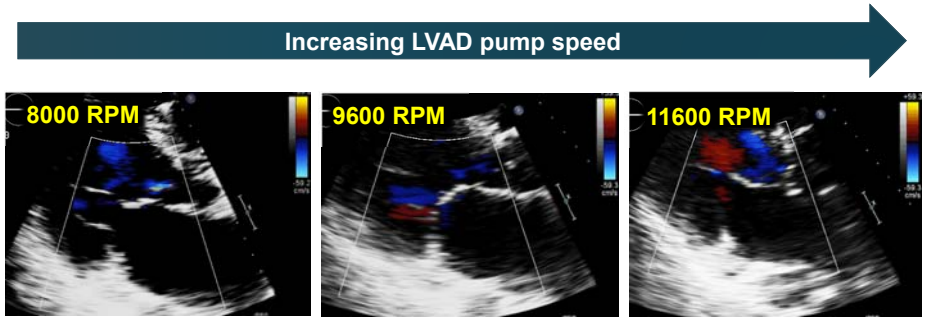
Optimization of Ao valve opening



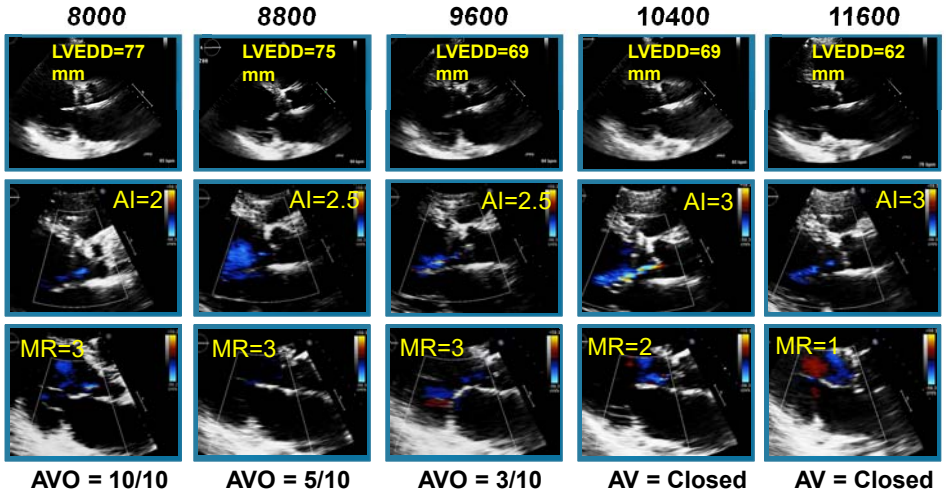
Optimization of Aortic Insufficiency



Optimization of Mitral Regurgitation



Example RAMP Study



Example RAMP Study

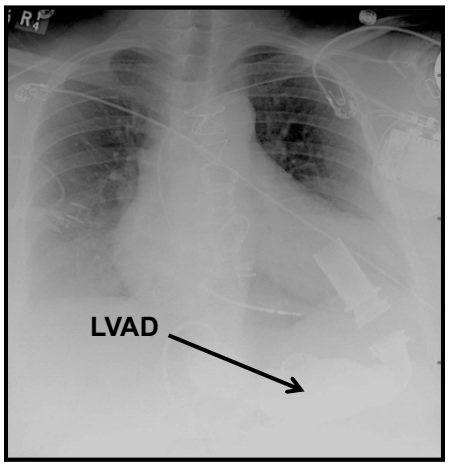
Speed	PI	Power	CVP	PAsys	PAd	mPAP	PCWP	PASAT	CO
8000	7.6	3.4	18	49	29	35	45	62.7	5.0
8800	7.8	4.3	18	46	28	33	25	66.1	5.58
9600	6.7	5.4	17	43	28	32	21	64.9	5.37
10400	6.6	7.0	16	40	27	32	20	66.8	5.71
11600	4.1	9.1	14	35	23	26	14	71.4	6.74

Speed	LVEDD	Septum	AVO	AI	MR
8000	77	Midline	10/10	2	3
8800	75	Midline	5/10	2.5	3
9600	69	Midline	3/10	2.5	3
10400	69	Midline	Closed	3	2
11600	62	Leftward	Closed	3	1

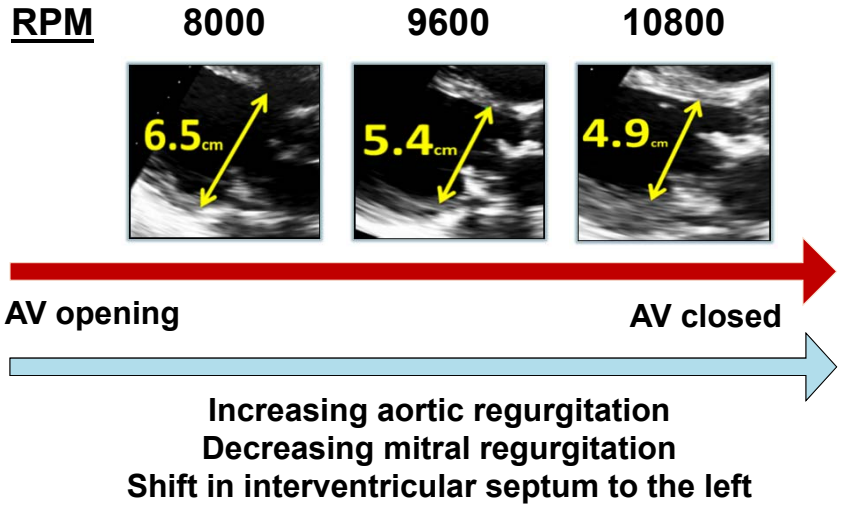
LVAD Malfunction: Case

LVAD Malfunction: A Case

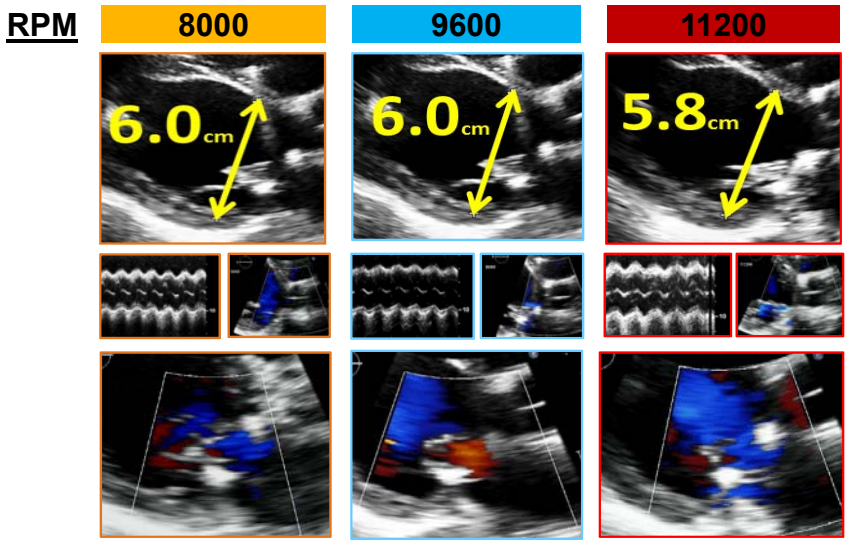
50 year-old female
- Idiopathic CM
- HMII 6 months ago
- 2-d history of shortness of breath and fatigue
- Labs consistent with hemolysis
- A RAMP study was performed



Recall: Normal LVAD Function



RAMP Study in our patient

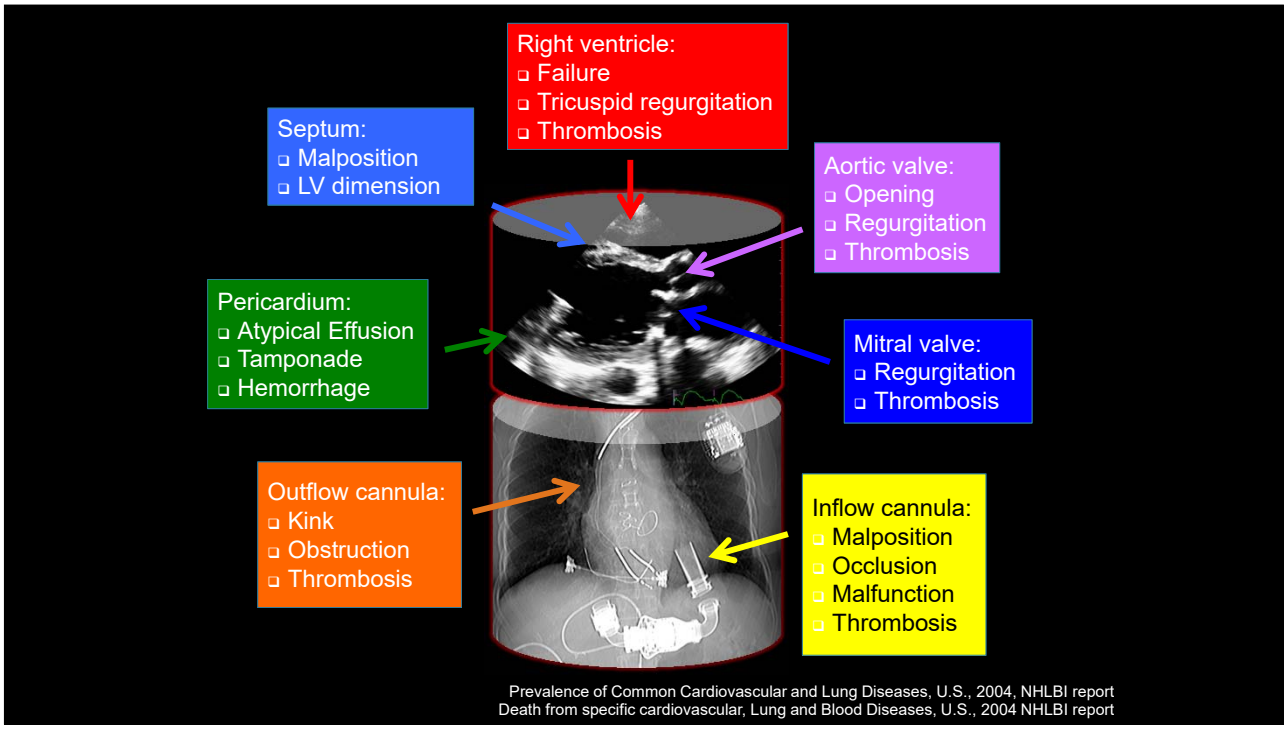


Device inspection in this patient

Visible thrombus in the inlet stator

Consider **LVAD thrombosis**:

1. Worsening HF
2. Signs of hemolysis
   - Elevated LDH
   - Low haptoglobin
3. Device malfunction (power spikes/flow alarms)
4. Echo-Ramp test demonstrates lack of change in LVEDD with increasing LVAD speeds


Right ventricle:
Failure
Tricuspid regurgitation
Thrombosis
Septum:
Malposition
LV dimension
Aortic valve:
Opening
Regurgitation
Thrombosis
Pericardium:
Atypical Effusion
Tamponade
Hemorrhage
Mitral valve:
Regurgitation
Thrombosis
Outflow cannula:
Kink
Obstruction
Thrombosis
Inflow cannula:
Malposition
Occlusion
Malfunction
Thrombosis
Prevalence of Common Cardiovascular and Lung Diseases, U.S., 2004, NHLBI report
Death from specific cardiovascular, Lung and Blood Diseases, U.S., 2004 NHLBI report


Thank-you for your attention